# AN EFFICIENT MODEL FOR NEAR-GROUND WAVE PROPAGATION IN THE PRESENCE OF BUILDING WALLS/INDOOR OBSTACLES

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## I. Introduction

Having models that could precisely predict electromagnetic fields in various environments is vital to the design of reliable wireless communication systems, for radar applications such as fire and earthquake rescue missions and distributed sensor networks for environmental sensing. In the literature, ray tracing has been used as the primary method to predict electromagnetic fields in indoor settings and other complex environments. Propagation models that combine ray tracing and empirical models with high frequency diffraction techniques such as GO/GTD/UTD have also been developed [1-2]. Most of the existing models use first order approximations as they do not take into account near-earth propagation effects, finiteness of walls and other indoor obstacles. In addition, when these methods are used, the error in the predicted field is higher at lower frequencies where the dimensions of indoor obstacles become comparable to the wavelength. Pure numerical techniques are not viable as they are computationally expensive for long distance near-earth propagation. In this work, an efficient semi-analytic technique to predict electric field for near-earth propagation in the presence of a building wall is developed for 2D case. To verify the accuracy of the new method, simulation results are compared with numerical solutions. A simpler yet more commonly used solution (based on ray tracing) is also presented for comparison.

## II. Formulation

Our primary objective in this work is to study the effect of dielectric building walls or similar indoor obstacles on the near-earth propagation of electromagnetic waves over a long distance. When the source and observation locations are close to the ground, even in the absence of a building wall, the direct field and the geometric-optics reflected wave (from ground) will not be sufficient to predict the observed electric field. Instead, other higher order contributions (Norton surface waves) dominate the total observed field. An asymptotic solution that takes these higher order terms into account is given in [3]. In the presence of a building wall, for a vertical dipole source, the total observed field is given below.

$$E_{x,y}^{observed} = E_{x,y}^{direct} + E_{x,y,ground}^{Scattered} + E_{x,y,wall}^{Scattered}\ ; \qquad (1)$$

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It should be noted that the field scattered by the building wall need to be computed in the presence of the ground (as part of the background medium). The approach we pursued to include this contribution to the total observed field is based on the volume equivalence principle. We first approximate the volumetric polarization current which will be determined by the incident field from the transmitting antenna and dielectric properties of the building wall. The fields from the polarization currents are then propagated forward to the observation point and are added together.

Both the propagation from the source to the wall surface and the forward propagation of the field of the polarization currents to the observation point are calculated by taking the near-ground propagation effects into account. This method allows the inclusion of Norton surface waves which will especially affect the volumetric polarization currents on the lower part of the wall and hence its contribution to the scattered field by the building wall. Fig. 1 shows the geometry of the problem considered with realistic dimensions and dielectric constant; simulation results are discussed in the next section.

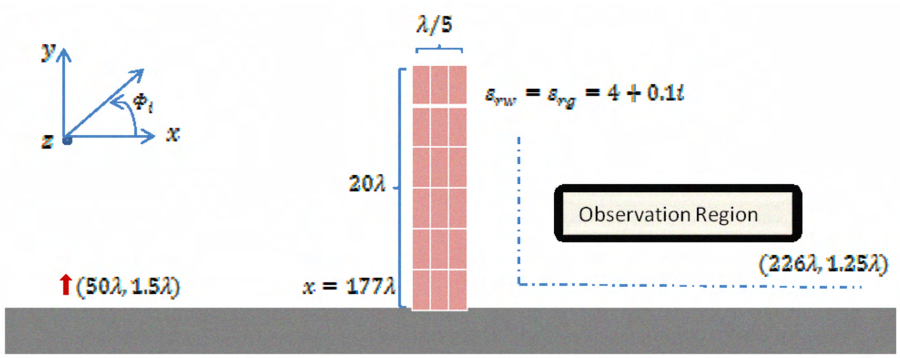


Fig. 1 Wall-ground problem geometry (various models to estimate the effective dielectric constant of a building wall based on experimental results exist [4] )

Physical optics approximation is used to estimate the total fields on the surface of the building wall. The incident field from an infinite electric line current illuminating the building wall is first calculated at the edge of the wall on the source side using the asymptotic 2D dyadic Green's function in the presence of a half-space dielectric. The total field inside the wall is computed by summing multiple reflections from the two edges of the wall (similar to a thin dielectric slab). The expressions for the total field inside the wall surface for the $TE_z$ case are given in equations 1 and 2 below. Similar expressions can be derived for the $TM_z$ case. In all the formulations $e^{-j\omega t}$ convention is assumed.

$$E_x = \left(\frac{-k_y}{\omega \varepsilon_w}\right)\left(A_w e^{ik_{wx}x} + B_w e^{-ik_{wx}x}\right)e^{ik_y y} \; ; \qquad (2)$$

$$E_y = \left(\frac{k_{wx}}{\omega \varepsilon_w}\right)\left(A_w e^{ik_{wx}x} - B_w e^{-ik_{wx}x}\right)e^{ik_y y} \; ; \qquad (3)$$

where,

$$B_w = \left(\frac{2k_{ox}\varepsilon_{rw}E^i(\Phi_i)}{k_{wx} + k_{ox}\varepsilon_{rw}}\right) \Big/ \left(1 - \left(\frac{k_{wx} - k_{ox}\varepsilon_{rw}}{k_{wx} + k_{ox}\varepsilon_{rw}}\right)^2 e^{i2k_{wx}d}\right);$$

$$A_w = \left(\frac{k_{wx}-k_{ox}\varepsilon_{rw}}{k_{wx}+k_{ox}\varepsilon_{rw}}\right) B_w e^{i2k_{wx}d} \qquad \& \qquad {k_{wx}}^2 + {k_y}^2 = k_w^2 ;$$

$k_{wx}$ and $k_y$ are the spatial frequencies on the wall surface and $\varepsilon_{rw}$ and d are the effective dielectric constant and the thickness of the wall respectively. The electric polarization current on the wall surface can be calculated using the dielectric constant of the wall based on the following equation.

$$J_{epx,y}(x_i, y_j) = -i\omega\varepsilon_0(\varepsilon_{\mathrm{rw}} - 1)E_{x,y}(x_i, y_j); \qquad (4)$$

After the polarization currents are calculated, the electric field scattered by the wall in the observation region is computed by integrating these currents using the asymptotic implementation of the 2D dyadic Green's function in the presence of a half-space dielectric to account for the effect of the ground. Then, the resulting field is added to the first two terms in equation (1) to get the total observed field.

## III. Simulation Results

The method was applied for various source positions to analyze how fields scattered from the ground and the building wall affect the total received signal. The Norton surface waves, being more prevalent close to the ground, affect the polarization currents on the lower part of the wall more. Therefore, non-uniform discretization was used to capture their effects on the polarization currents on the lower part of the wall while keeping the computation time to a minimum. To verify the accuracy of the method, we used a numerical solution based on the Nyström method. The more commonly used ray tracing (based on geometrical optics) is also implemented to see if indeed the physical optics approach is superior. As can be seen in the figures below, the new field predictor gives results that are very close to the numerical solution and the comparisons proved that ray tracing is not a good technique especially when the sources are close to the ground where the Norton surface waves affect the observed field significantly. In terms of computational cost, the physical optics approach has proved to be at least five times faster when it is compared with the numerical method.

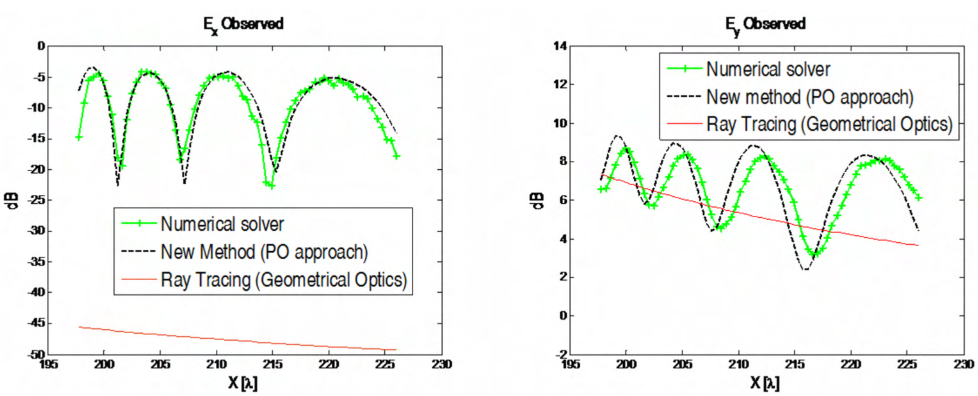


Fig. 2 Electric field comparison (an electric line current of y-directed dipoles was used as a 2D source, $\varepsilon_{rw}$=$\varepsilon_{rg}$= 4+0.1i, see Fig. 1 for geometry)

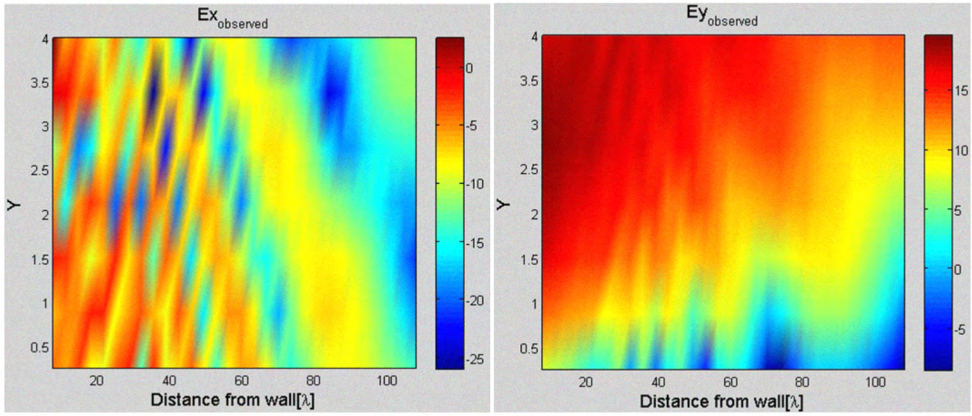

Fig. 3 $x$ and $y$ components of the total electric field (dB) in the observation region for a y-directed dipole source (see Fig. 1 for geometry)

## IV. Conclusion

A semi-analytic model for near-earth wave propagation in the presence of building walls or similar obstacles is devised. The method is based on physical optics type approximations used in conjunction with the volume equivalence principle. Norton surface waves that are typically neglected in more common indoor propagation techniques such as ray tracing are included in this method as they prove to be vital for the accurate prediction of fields especially for sources close to ground. Simulation results have shown that, this method gives much more accurate results than ray tracing and proves to be computationally better than a numerical method and hence could be used to analyze field propagation in indoor structures that are large in terms of wavelength.

## V. References

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